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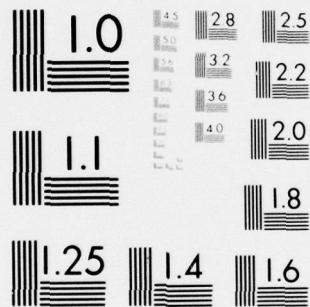
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FINAL TECHNICAL REPORT

SURFACE CHARGE STABILITY ON FUSED SILICA

D.H. Baird

December 1976

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ABSTRACT

The stability of electric charge adsorbed on a fused quartz surface has been studied. In particular, the effects of electric field strength, radiation, and ambient gas pressure have been investigated. It is found that transfer to or from the surface of sufficient charge to neutralize an external electric field occurs readily under ultraviolet radiation. Evidence is presented that changes in surface charge in the presence of a gas ambient occur when the electric field at the surface exceeds the breakdown field of the gas. Partial discharges then occur which alter the surface charge in such a way as to reduce the field below the breakdown value.

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INTRODUCTION

This report describes a brief investigation of the storage and transport of charge on or near glass surfaces. Interest in this phenomenon was prompted by observations of a pulsed conduction process occurring between electrodes on a glass surface under the application of dc voltage. The observation that light and heat increase the pulse rate suggested that the process involved the freeing of electrons from surface traps under the combined influence of the applied electric field and radiative or thermal activation.

Experiments under controlled atmosphere indicated that this process was enhanced by conditions favoring ionization of the gas in contact with the surface. This implied that the phenomenon involves the transfer of charge from the surface to the gas. To seek further evidence for such transfer, experiments were performed in which the magnitude of the charge on a glass surface could be measured as those parameters which control the pulsed conduction were varied. The experimental approach and results of this study are described below. The extension of this study in the direction of surface charge phenomena on glass was made in preference to the exploration of electron pooling effects at liquid surfaces, which had been under consideration earlier. The results of the study of the pulsed conduction process itself formed the basis for an invention disclosure describing a controllable random noise generator.

Experimental Method of Surface Charge Measurement

The technique used for measurement of the surface charge is a modification of the Kelvin method similar to that described by Williams and Willis.¹ The design and operation of the experimental cell is illustrated schematically in Figure 1. The specimen is a fused silica plate, about 2 mm thick, which forms one wall of the vacuum cell. The charging and discharging processes under study take place on the inner surface of this plate. Within the cell and close to this surface is a nickel mesh electrode which can be made to oscillate in a direction perpendicular to the surface and thus has a varying capacitive coupling to it. The oscillating motion is transmitted through an insulated vacuum bellows. A cam drives the oscillation at 1 Hz. The external surface of the fused silica plate carries a semitransparent platinum coating which serves as a counter-electrode coupled capacitively to the inner surface and to the oscillating electrode. The transparency of this electrode permits introduction of

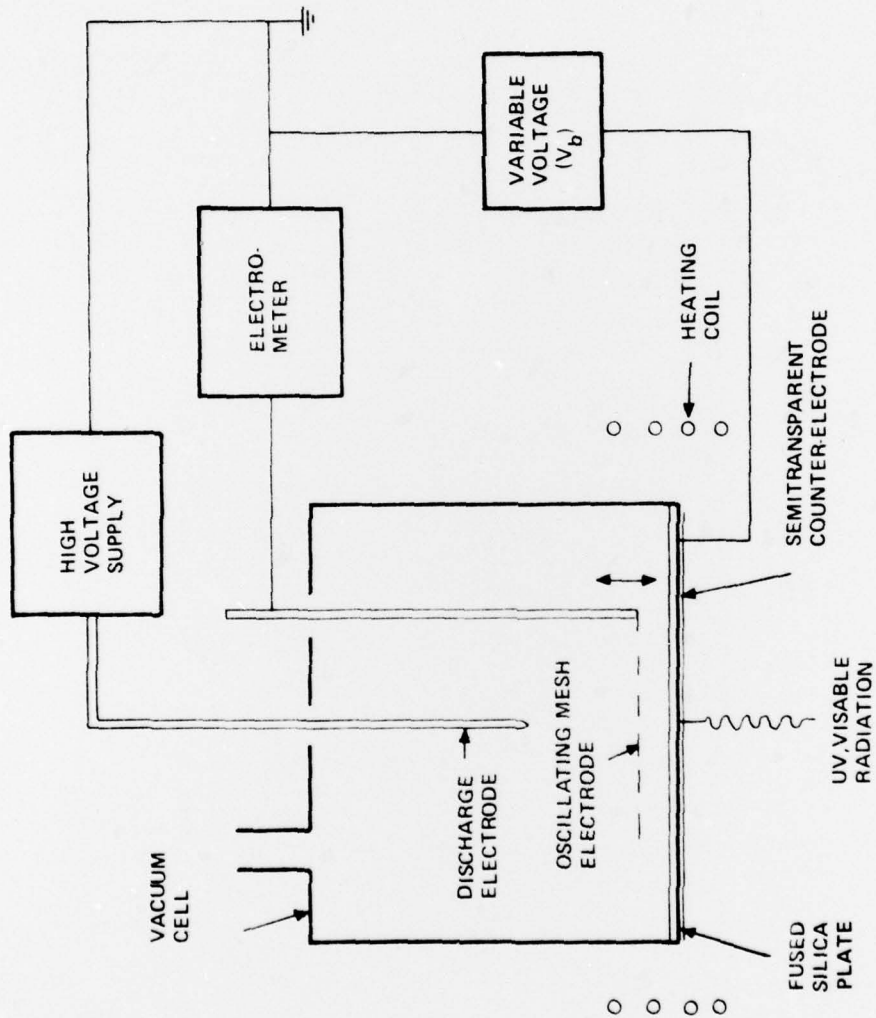


Figure 1. Experimental Arrangement for Surface Charge Measurement

radiation into the cell. Resistive heating may be used to vary the temperature. Operation can be in either a vacuum or a controlled gas ambient. A corona discharge at a high voltage electrode within the cell affords a convenient means of providing charge for deposition on the surface under study.

In operation, the movable electrode is connected to an electrometer. If the electrometer input is momentarily grounded at some position of the oscillating electrode where its capacity to the counter-electrode is C_T , then the voltage V_{el} across the electrometer at some other position of the electrode where this capacity is $C_T - \Delta C_T$ is

$$V_{el} = - \frac{\left(V_b + \frac{q_s}{C_p} \right) \Delta C_T}{C_i + C_T} \quad (1)$$

where V_b is the bias voltage applied to the counter-electrode, q_s is the charge on the internal surface of the fused silica plate, C_p is the capacity across this plate and C_i is the total capacity between the movable electrode and ground. This relation assumes that the variation ΔC_T occurs in a time short compared with the RC time constant of the electrometer circuit, typically of the order of one hour. The determination of q_s depends on the fact that the electrometer voltage no longer varies with the position of the movable electrode when

$$V_b = - \frac{q_s}{C_p} \equiv V_n \quad (2)$$

Measurement is made by observing the electrometer output on an oscilloscope or meter as the motion of this electrode produces cyclic changes in C_T . Adjustment of V_b , the voltage of the counter-electrode, to a value producing a null in the variation of electrometer output with electrode position yields V_n and thus q_s . Expressing the result as a surface charge density, σ_s ,

$$\sigma_s = - \frac{V_n \epsilon}{t} \quad (3)$$

where ϵ and t are the dielectric constant and thickness of the silica plate, respectively. Typically for fused silica, $\epsilon/\epsilon_0 = 4$. With $t = 2$ mm we have

$$\begin{aligned}\sigma_s &= -(1.8 \times 10^{-12}) V_n \text{ coul/cm}^2 \\ &= -10^7 V_n |e|/\text{cm}^2\end{aligned}\tag{4}$$

where $|e|$ is the magnitude of the electron charge and V_n is expressed in volts.

Several sets of data were obtained at different levels of surface charge density to confirm the applicability of Eq. (1) by measuring V_{el} as a function of V_b . Figure 2 shows two plots of this relation when σ_s is close to zero, one measured under vacuum and one at one atmosphere of argon. The small value of σ_s is shown by the fact that V_{el} vanishes near $V_b = 0$. The slope of the vacuum curve is somewhat the higher of the two. According to Eq. (1), this slope is $\Delta C_T/(C_i + C_T)$ and the difference is apparently produced by a change in ΔC_T due to a slight flexing of the silica plate under vacuum. The validity of the measurement is not affected since both curves yield the same value of V_n and hence of σ_s . The curve in Figure 3 was obtained with the silica surface negatively charged resulting in a shift of the zero in the electrometer output to a counter-electrode voltage of 1275 V. This curve was obtained at one atmosphere pressure and has the same slope as the one atmosphere curve in Figure 2.

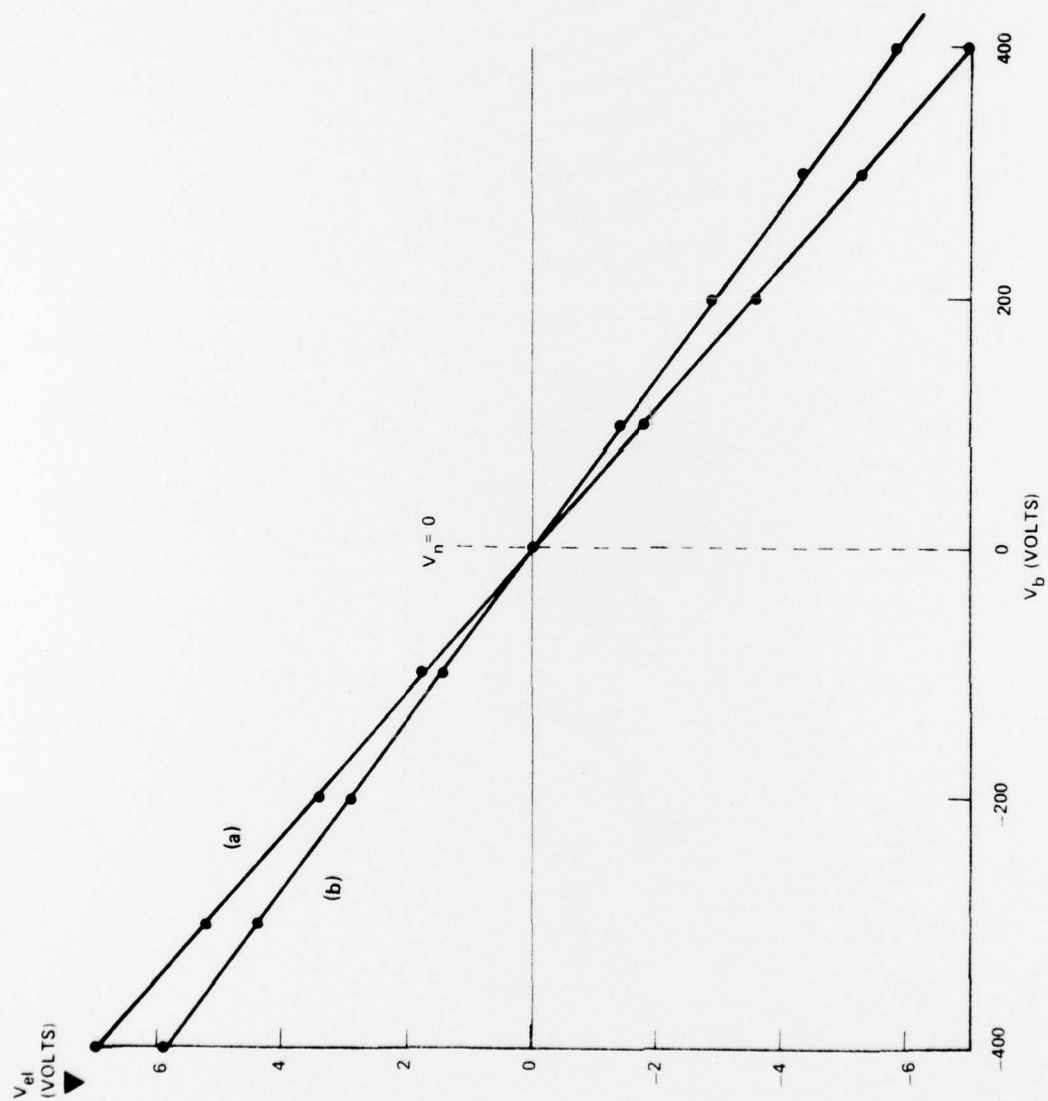


Figure 2. Electrometer Voltage V_{el} vs. Counter-electrode Voltage V_b for Zero Surface Charge
 (a) in Vacuum
 (b) at 1 Atmosphere Argon

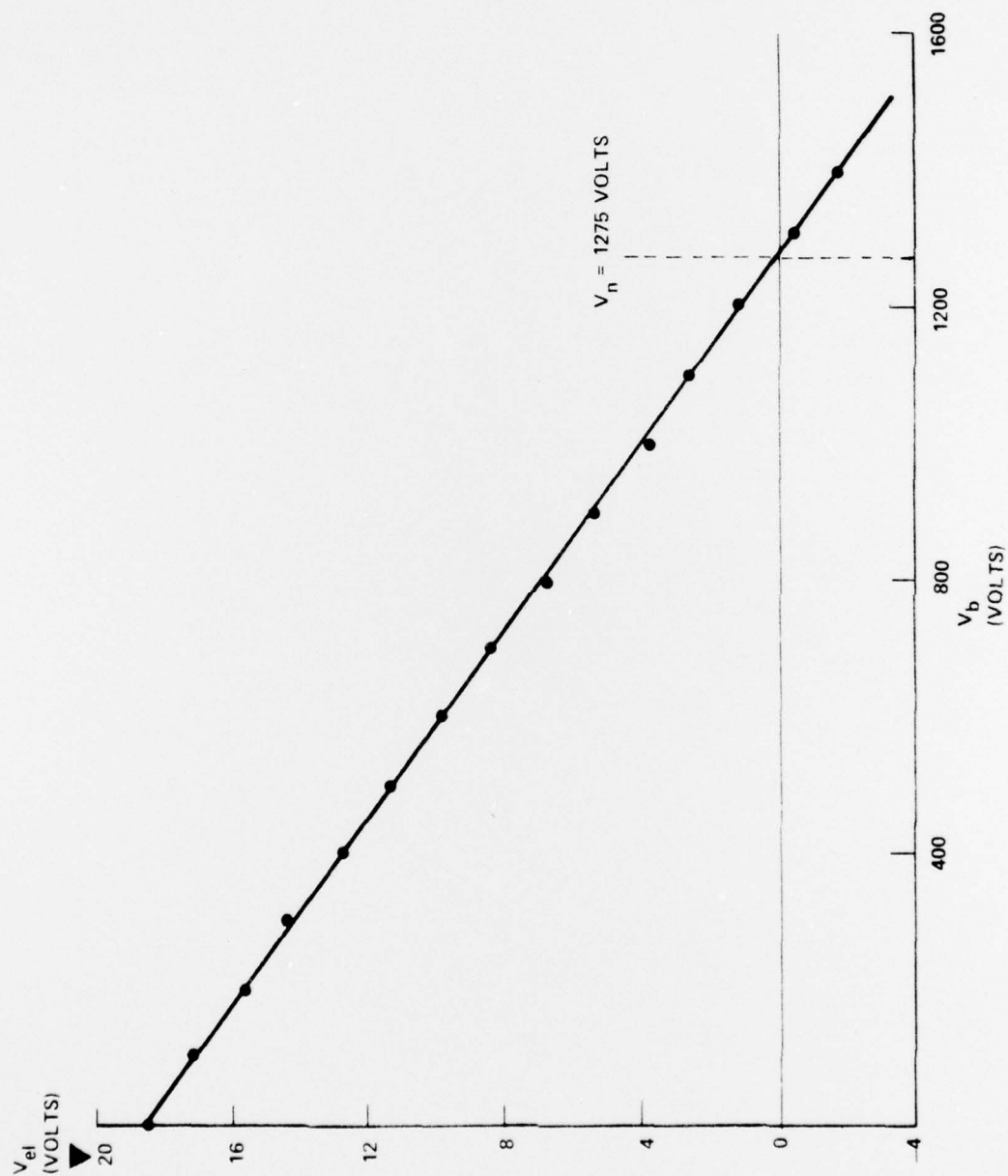


Figure 3. Electrometer Voltage V_{el} vs. Counter-electrode Voltage V_b for Negative Surface Charge

RESULTS

Measurements were initiated to identify the factors to which adsorption and desorption of the surface charge are most sensitive. The results to date are described below.

Changes in surface charge density have been produced with two different sources of mobile charge: (1) a discharge at the high voltage electrode, and (2) photoelectric emission induced by ultraviolet radiation. With respect to the latter process, it appears that in the presence of light of sufficient quantum energy, charge transfer occurs between the silica surface and the movable electrode until the electric field between them vanishes. If the counter-electrode voltage is positive, this requires the addition of negative charge to the silica surface, presumably by photoelectrons emitted from the movable electrode. If the counter-electrode is negative, the reverse direction of current flow occurs, possibly by photoemission of electrons from the silica surface itself. Sufficient surface charge has been induced in this way to neutralize counter-electrode voltages ranging from -500 to +500 volts. These changes occur readily in vacuum.

Both positive and negative discharges have been used to deposit surface charge. Most experiments to date have involved use of a negative discharge in low pressures of argon. As in the photoemissive process, the voltage on the counter-electrode can be used to control the charging level. In this case, the control is less exact, and the magnitude of the resulting surface charge is normally greater than that required to neutralize the counter-electrode voltage.

Perhaps the most striking observations have been of the dependence of surface charge dissipation on the pressure of the gas and on the electric field within the cell. It should be noted that when the counter-electrode voltage is adjusted to the value V_n which nulls the output of the movable electrode, there is no field between the silica surface and this electrode. If the counter-electrode voltage is then adjusted to some other value, V_b , the field inside the cell near the silica surface is proportional to $|V_b - V_n|$ for a given position of the movable electrode. In vacuum at room temperature, negative surface charge is stable for values of $(V_b - V_n)$ of at least 5000 V. However, in the presence of argon, partial loss of surface charge can occur at much lower values, depending on both the argon pressure and the position of the movable electrode.

This was illustrated by experiments of the following kind. At a given pressure of argon, V_b was set at about +1000 V and a negative discharge operated in the cell. Under these conditions, adsorption of negative surface charge occurs to yield a value of V_n near 1000 V. The movable electrode was then stopped at a selected position and V_b reduced slowly to zero. In general, V_n is reduced to some remanent value V_o in the course of this process, due to loss of surface charge. V_o is a measure of the electric field at the surface when V_b is zero. In Figure 4, V_o is plotted as a function of argon pressure for three positions of the movable electrode. It can be seen that for each electrode position, V_o shows a minimum as a function of pressure, the minima moving to increasing pressure as the distance between the fused silica surface and the electrode is increased. Also the value of V_o at the minimum increases with increase of this distance.

It is probable that these results are a reflection of Paschen's law relating breakdown voltage in a gas to pressure and electrode spacing. The remanent surface charge is determined by the maximum field the gas can support without breakdown. According to this model, when the field due to the surface charge exceeds the breakdown field, a partial discharge occurs in the gas near the surface and the charged species formed in the discharge neutralize part of the surface charge. The relative positions of the minima of the various curves as well as the relative magnitudes of V_o at the minima are in qualitative agreement with this picture. A similar explanation has been proposed for the partial discharge of electrets at reduced pressure.²

If this is the correct explanation, a further significant question exists concerning the role played by the surface in triggering such partial discharges and the extent to which this role is affected by the state of the surface. Such a role might depend, for example, on the availability of relatively loosely bound surface charge. A desirable extension of the present work is the exploration of the effects of temperature variation of the surface during or after the time when the surface charge is laid down.

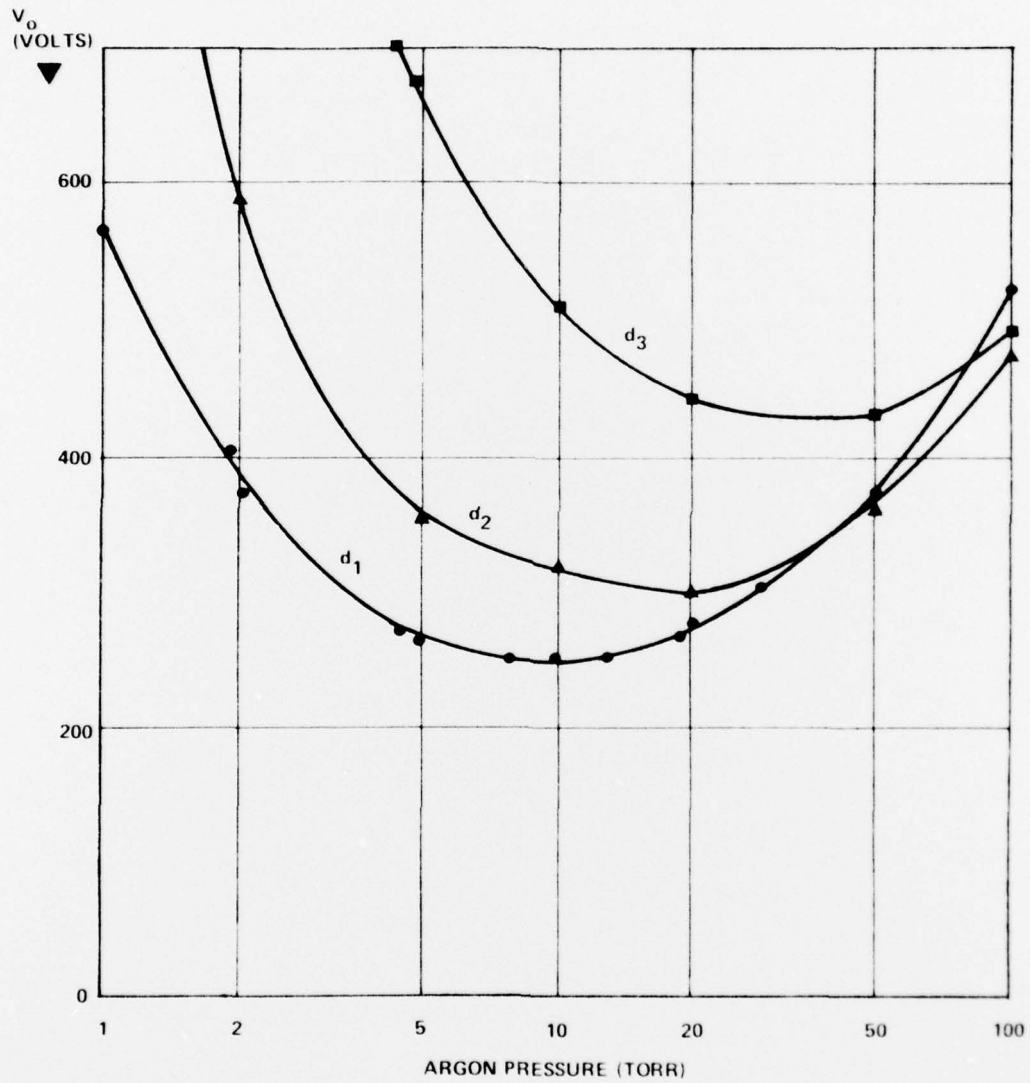


Figure 4. V_o vs. Argon Pressure. Electrode to Surface Spacings: $d_1 > d_2 > d_3$

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